LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-CONF-414543

Comparison of WDM/Pulse-Position-Modulation (WDM/PPM) with Code/Pulse-Position-Swapping (C/PPS) Based on Wavelength/Time Codes

A. J. Mendez, V. J. Hernandez, R. M. Gagliardi, C. V. Bennett

July 9, 2009

Avionics, Fiber-Optics and Photonics Conference 2009
San Antonio, TX, United States
September 22, 2009 through September 24, 2009

Disclaimer

COMPARISON OF WDM/PULSE-POSITION-MODULATION (WDM/PPM) WITH CODE/PULSE-POSITION-SWAPPING (C/PPS) BASED ON WAVELENGTH/TIME CODES

Antonio J. Mendez[a], Vincent J. Hernandez[b], Robert M. Gagliardi[c], Corey V. Bennett[b]
[a]Mendez R&D Associates, El Segundo, CA
[b]Lawrence Livermore National Laboratory, Livermore, California
[c]University of Southern California, Los Angeles, CA

Introduction

Pulse position modulation (PPM) signaling is favored in intensity modulated/direct detection (IM/DD) systems that have average power limitations [1]. Combining PPM with WDM over a fiber link (WDM/PPM) enables multiple accessing and increases the link's throughput. Electronic bandwidth and synchronization advantages are further gained by mapping the time slots of PPM onto a code space, or code/pulse-position-swapping (C/PPS) [2-4]. The property of multiple bits per symbol typical of PPM can be combined with multiple accessing by using wavelength/time [W/T] codes [5] in C/PPS. This paper compares the performance of WDM/PPM and C/PPS for equal wavelengths and bandwidth.

Technical Discussion

The data rate R_p for conventional M-ary PPM signaling is given by

$$R_p=(\log_2 M)/(MT_s)$$

where T_s is the slot time. The throughput Th_p for WDM/PPM with W wavelengths (and therefore W users) is then

$$Th_p=WR_p=(W\log_2 M)/(MT_s)$$

In this part of the discussion we assume $M=32$ and $W=8$ (later, in the discussion associated with Fig.1, we let M and W vary from 4 to 32). Corresponding expressions for data rate R_c and throughput Th_c for C/PPS with k concurrent users are:

$$R_c= (\log_2 M/k)/(4T_c)$$

$$Th_c=kR_c=(k\log_2 M/k)/(4T_c)$$

where T_c is the chip time of the codes used, which have a code set cardinality of 32, each with a code length of $4T_c$, based on $W=8$ [5]. If we now assume equal electronic bandwidth (i.e., $T_s=T_c$), then $R_c>R_p$ when $k=1$ (C/PPS is, after all, a form of bit-parallel transmission). $Th_c=Th_p$, but WDM/PPM has more concurrent users (8). If we consider the case of C/PPS where the number of users equals the number of wavelengths ($W=k=8$), then $R_c>R_p$ and $Th_c > Th_p$. This solution is equivalent to 4-ary C/PPS with eight users ($k=8$), and our previous work on virtual quadrant 16-ary receivers [6-8] is applicable. Fig. 1 shows a comparison of the data rates and the throughputs when $T_c=T_s$, plotted against the number of wavelengths (which is the same as the number of users in the case of WDM/PPM). The crossover for $R_c>R_p$ occurs at six wavelengths because of the construction of the W/T codes. R_p is monotonically decreasing because the frame time is increasing with M, whereas the frame time for C/PPS is either constant or decreasing. In addition, the number of codes are increasing with W. The throughput for C/PPS exceeds that of WDM/PPM ($Th_c>Th_p$), but the number of concurrent users is less for C/PPS than for WDM/PPM. Fig. 1 also includes the throughput when C/PPS has the same number of users as wavelengths. C/PPS still has a higher throughput; however, this is at the expense of multiuser interference [8], which will affect quality of service (QoS).

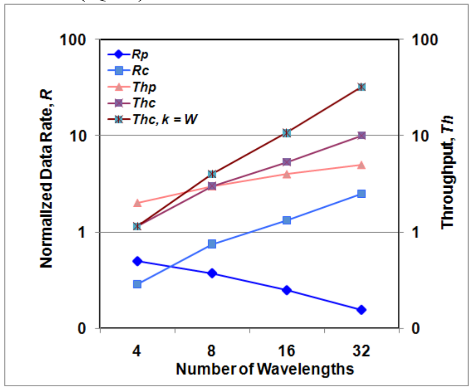

Figure 1. Data Rate and Throughput Comparison of WDM/PPM and C/PPS.

Summary and Conclusions

C/PPS is a flexible multibit per symbol modulation format. It has the same architecture as PPM, but has greater bandwidth efficiency. It can utilize a code set to maximize the data rate of a particular user or distribute its codes to various users at different data rates. In the latter case, it is important to consider the associated effects on QoS. C/PPS is less sensitive to synchronization than PPM because the code defines the slot, independent of time-of-arrival. More research on virtual quadrants [6, 7] and multiuser detection [9] is needed for C/PPS because the C/PPS transmission is broadcast-like and all decoders have signals.

Acknowledgement

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-7NA27344. This work was funded in part by DARPA SBIR Phase II Adoption contract W31P4Q-05-C-R161. LLNL-CONF-414543

References

[1] R. M. Gagliardi and S. Karp, *Optical Communications*, 2nd ed., John Wiley and Sons, New York, 1995.

[2] E. Narimanov, *Optical Code Division Multiple Access: fundamentals and applications*, pp. 106, CRC Taylor & Francis, Boca Raton, FL., 2006.

[3] S. Galli, R. Menendez, E. Narimanov, and P. Prucnal, "A novel method for increasing the spectral efficiency of optical CDMA," *IEEE Trans. Commun.*, vol. 56, no. 12, pp. 2133-44, 2008.

[4] X. Wang, N. Wada, T. Miyazaki, G. Cincotti, and K. i. Kitayama, "Asynchronous multiuser coherent OCDMA system with code-shift-keying and balanced detection," *IEEE J. Sel. Topics Quantum Electron.*, vol. 13, no. 5, pp. 1463-70, 2007.

[5] A. J. Mendez, R. M. Gagliardi, V. J. Hernandez, C. V. Bennett, and W. J. Lennon, "High-performance optical CDMA system based on 2-D optical orthogonal codes," *J. Lightw. Technol.*, vol. 22, no. 11, pp. 2409-19, 2004.

[6] A. J. Mendez, V. J. Hernandez, R. M. Gagliardi, and C. V. Bennett, "Design and Evaluation of a Virtual Quadrant Receiver for 4-ary Pulse Position Modulation/Optical Code Division Multiple Access (4-ary PPM/O-CDMA)," in *Proc. SPIE*, vol. 6457, 2007, 64570H-1-6.

[7] A. J. Mendez, R. M. Gagliardi, V. J. Hernandez, and C. V. Bennett, "Receiver Architecture for 12.5 Gb/s 16-ary Pulse Position Modulation (PPM) Signaling," in *Proc. IEEE Avionics, Fiber-Optics, and Photonics Technology Conf. (AVFOP)*, 2008, pp. 59-60.

[8] V. J. Hernandez, A. J. Mendez, R. M. Gagliardi, C. V. Bennett, and W. J. Lennon, "Performance Impact of Multiple Access Interference in a 4-ary Pulse Postion Modulated Optical Code Division Multiple Access (PPM/O-CDMA) System," in *Proc. IEEE Optical Fiber Communications Conf. (OFC)*, 2008, 1652-4.

[9] S. Verdu, *Multiuser detection*. Cambridge Unversity Press, 1998